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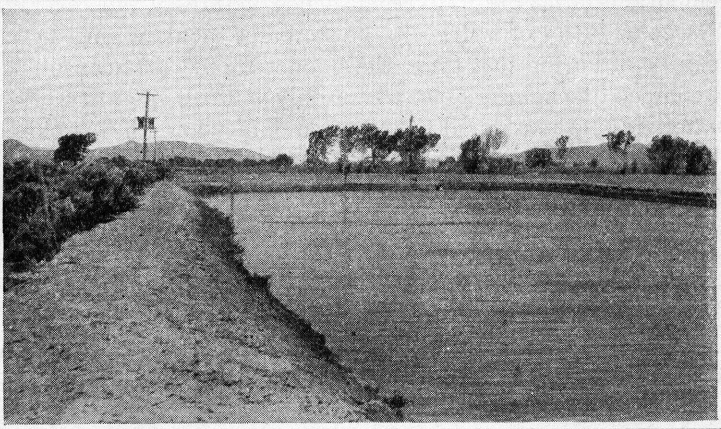
RESERVOIRS *for* FARM USE



MOST FARM reservoirs are used to supply water for irrigation, for livestock, and domestic use, and as swimming pools and fish ponds. This bulletin describes the construction and maintenance of such reservoirs, to be used for the storage of comparatively small quantities of water.

The builder of a dam must comply with the laws and regulations of his State covering such structures. Wherever a large quantity of water is to be stored or the dam must be high or of an unusual type, the builder should first consult a competent engineer, but where only a small quantity of water is to be stored and the required dam is low, the simple instructions given in this bulletin should enable a farmer to plan and build his own reservoir.

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RESERVOIRS FOR FARM USE

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USES OF FARM RESERVOIRS

FARM RESERVOIRS are most commonly used in connection with pumping plants, since it is often desirable or necessary to use pumps of rather small capacity, especially to pump water from wells. Careful consideration should be given to the type and size of the pump.[1] In areas where it is not possible to obtain wells yielding large quantities of water, it is possible, by continuous pumping, to impound enough water in reservoirs to irrigate a pasture and a garden. Figure 1 shows a reservoir filled by pumping with windmills.

Under some irrigation systems water is delivered on a rotation schedule, and unless a storage reservoir is provided livestock can be watered in the interval between irrigations only by pumping from wells. In many places in the arid States considerable pasture is available if water for livestock can be found. Often it is possible to fill small reservoirs with water from the spring run-off or from intermittent rains, and livestock can then be grazed on the adjoining range and watered from these ponds.

Small ponds often may be used for recreational purposes. Ponds used for storing irrigation water may be used also as swimming pools, and some ponds are stocked with fish. If the water stands in ponds for more than a week at a time, there is always the possibility of mosquito breeding. Certain species of small fish will feed on the mosquito larvae and help very materially in abating this nuisance.

WATER SUPPLY

Water for small farm reservoirs may be obtained from pumped wells or from flowing wells. If a flowing well is located below the land to be irrigated, it may be necessary to pump water to the higher ground. If the discharge from the well is small the reservoir should be located on high ground rather than on low ground adjacent to the well. If the well is on high ground a small pump can be used to fill the reservoir, but if the reservoir is on low ground a large pump is necessary to supply sufficient flow for efficient irrigation.

[1] Information on pumps and wells is contained in Farmers' Bulletin 1404, Pumping from Wells for Irrigation.

Likewise the water from a spring on high ground may sometimes be impounded in a reservoir below the spring and above the land to be irrigated. If the spring is on the lower ground it will be best to locate the reservoir on high ground and install a pump at the spring to fill it.

Occasionally the discharge of a spring is small and spread out over such an area that the only sign of water is a swampy patch of ground with a growth of rank vegetation. Such a so-called "seep spot" may be excavated and the water allowed to accumulate in the excavation until sufficient volume has accumulated to provide a good irrigation stream.

It is sometimes feasible to store the spring run-off from small areas on individual farms. Where the rainfall comes in torrential downpours, it may be possible to store the surface run-off. In regions of

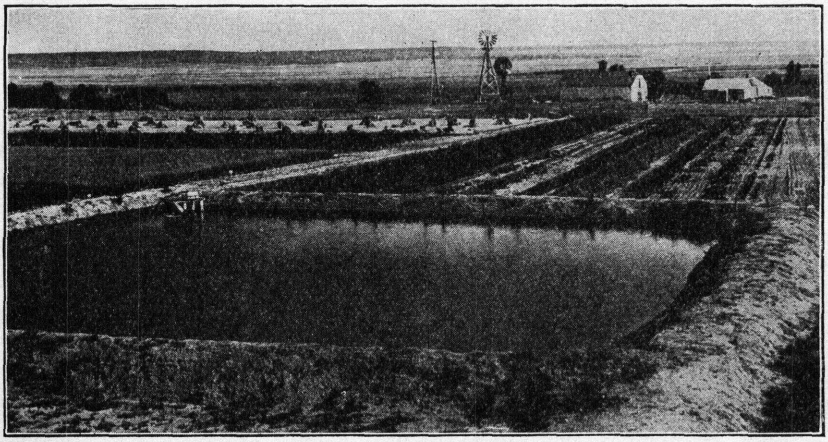

FIGURE 1.—Earthern reservoir filled by pumping with windmills, Cheyenne, Wyo.

light rainfall water from comparatively large areas may sometimes be collected in small reservoirs and used for irrigation.

In some areas small perennial streams may be used to fill farm reservoirs. In the more humid sections the discharge of small streams which normally do not carry enough water for satisfactory irrigation may be stored and used for irrigation or other purposes.

Some irrigation canals are operated on a "continuous-flow" basis. Under this system an individual farm may be entitled to a stream of water too small for certain types of irrigation. If the continuous stream can be stored in a reservoir for a few days, better results may be obtained. In other cases gravity canals may deliver water during periods of flood run-off faster than it can be used economically for irrigation, and the excess may be stored in small reservoirs and used later.

CHOOSING THE SITE

Often a reservoir may be constructed by building a dam across the channel of a stream which seldom carries water. Occasionally it is possible to find depressions through which no streams flow but which are suitable sites for small reservoirs. If there is no natural depression it will be necessary to build up an embankment and thus create a pond. Such construction is more expensive than where a natural site

can be had. However, it often is economically feasible to build reservoirs on either sloping or level ground.

The site on which the reservoir is to be built will greatly influence the character of construction. In deciding on a proposed site, the first consideration is to determine tentatively the location and dimensions of the required dam. If its height and length are not too great to be practical the next problem is to determine whether the proposed reservoir will hold water. Generally the tract will be suitable for a small storage reservoir, if it already is holding some water or is traversed by the channel of a stream which does not lose water rapidly by deep percolation. In areas where the underlying rock is either limestone or lava, or where there are large deposits of gypsum, special care should be taken to determine the water-holding character of the site. Depressions in such areas often are caused by the collapse of caverns formed by the dissolving of limestone or gypsum, and an attempt to store water in such a place is likely to fail.

Sometimes a satisfactory reservoir can be built even over porous or cavernous rock if the soil cover is very thick. When the construction can be carried on in stages, storage of water at each stage may demonstrate the ability of the formation to hold water, but even then there will be danger that as larger volumes of water are stored the increased pressure may cause a break into some underground channel and the undertaking may fail.

If the site of the reservoir is reasonably watertight, the next step is to investigate the foundation for the dam or levee. To determine the nature of the subsoil, pits should be dug several feet deep unless solid rock is encountered. In addition to the pits, a number of borings may be made with post-hole or soil augers. The construction of the dam will depend very largely on the conditions shown by these examinations.

Perhaps the most satisfactory type of site is a small rocky canyon across which a tight dam can be built with its upstream face sealed into solid rock throughout its length. In such locations, dams made of watertight material, generally concrete but occasionally either metal or wood, will be most satisfactory. Where the dam is to be of earth, a tight clay subsoil is a satisfactory foundation. If the subsoil is composed of sand or gravel, it will be necessary to take this condition into consideration.

LEGAL REQUIREMENTS

In most Western States it is necessary to procure a right to store water. The only exceptions are where water is pumped from underground or obtained from a spring that does not flow off the owner's land. In some States a permit must be secured before wells are drilled or sunk. In the humid sections of the United States no application for the right to store water need be made, but the natural flow of surface streams must not be changed to the injury of owners of riparian tracts farther downstream.

Many States have regulations governing the construction of dams for the storage of water. Generally, in the Western States, supervision of the building of dams is entrusted to the State engineer. In States where water-right applications are not necessary the local district attorney will generally know whether permission to construct a storage reservoir is required. In a number of States where super-

vision is vested in the State engineer, he must approve plans for any dam more than 10 feet high or intended to store more than a few acre-feet of water.

EARTH DAMS

The material to be used in an earth embankment demands careful consideration. Since the cost of moving dirt increases with the haul, material close to the dam site should be used. The best material is a sandy or gravelly clay. Clay alone is not satisfactory. If the dam is to be built by hydraulic fill (p. 5) clay cannot be used alone because it does not give up the water readily and the material remains more or less fluid and cannot be built up. If the material forming the central mass of a hydraulic-fill dam consists of clay it is impossible to draw off the water. The fluid mass may then break through the coarser material forming the sides, destroying the structure.

Even where the material is placed by machinery, clay without sand or gravel is not satisfactory as it shrinks and cracks on drying and swells when wetted. On the other hand, sands and even sandy loams are not entirely satisfactory because they are not sufficiently watertight. Sometimes both clay soil and sandy soil are available. When both are used they should be mixed thoroughly. This may be done by spreading a layer of one type of soil 2 or 3 inches thick, and over this a similar layer of the other type, and thoroughly mixing the two with harrows or disks. If layers are left unmixed, water will seep through the sandy layers and cause trouble. A satisfactory dam can be made of almost any type of earth if the embankment is thick enough and is built up carefully.

Three factors determine the height of the dam: (1) The reservoir must hold the required quantity of water when the water surface is at the level of the bottom of the spillway; (2) the water level in the reservoir during flood periods must be high enough to produce the necessary flow in the spillway (this problem is discussed under Spillways); (3) the dam must be enough higher than the extreme high-water level to be safe against overtopping by waves. If the reservoir is very small or well protected the danger from wave action may be negligible. In most farm reservoirs a freeboard of 3 to 5 feet above high-water level should be sufficient. On large reservoirs, especially where strong winds blow, the freeboard should be increased, possibly to 15 feet or more.

No matter how carefully an earth dam is built it will settle during the first few years after it is constructed. To provide for settling, the embankment should be 10 percent higher than will be required after complete settling has taken place.

The width of the earth embankment will depend on its height. A dam not over 15 or 20 feet high should have a top about 6 feet wide; if a roadway is to be provided the width should be 8 or 10 feet. For embankments 6 or 8 feet high a width of 3 feet may be sufficient. The slope on the upper or water side should be about 3 horizontal to 1 vertical and on the downstream side about 2 horizontal to 1 vertical. If these slopes are used, the width at the bottom of the dam will be equal to the width at the top plus five times its height.

Figure 2 shows a cross section through the outlet pipe of a typical earth-fill dam.

An earth dam may be constructed by either mechanical or hydraulic methods. Where conditions are suitable and proper material

is available, the hydraulic method is very satisfactory, but conditions are seldom favorable for its use.

Where the earth embankment is to be built with machinery the best plan is to spread the earth in layers not over 6 inches thick and roll or otherwise compact each layer thoroughly. The material should be somewhat moist when it is placed. Sometimes, if it is too dry, a stream of water may be run into the borrow pit at night putting the material into good condition to be placed the next morning. Each layer should be spread the full width of the embankment and the central portion kept a little lower than the edges. The embankment should not be constructed in sections nor the earth dumped in the center and allowed to make its own slope. Ordinarily, after each layer has been placed and compacted, the surface should be left rough so that the next layer will bond well with it. A good roller for this operation may be made of a piece of corrugated-iron culvert filled with concrete, with a piece of pipe through the center as an axle. Another satisfactory roller can be made by placing an axle through several cast-iron car wheels. The roller should be drawn back and forth along the dam (crosswise of the stream channel) and the corrugations left will insure a better bond with the next layer than if a

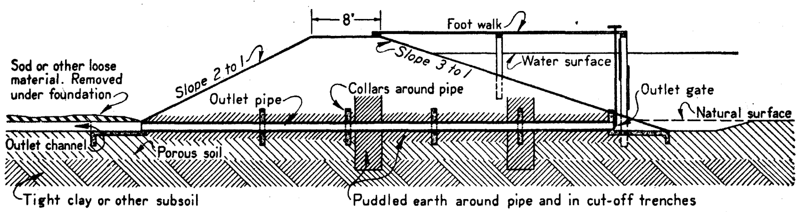

FIGURE 2.—Cross section of earth embankment.

smooth-faced roller is used. Sometimes a wheel tractor may serve as a roller. When horses or mules are used on the work their tramping assists materially in compacting the earth.

If the dam is to be built by the hydraulic-fill method, one or both of two plans can be used. Under one plan the edges of the embankment are built up with scrapers pulled by teams or tractors and the water-borne material is washed into the center of the dam between the two banks thus constructed. The excess water must be carried off by a pipe or a flume over one of the embankments. Under the other plan water carries all the material into the dam. Flumes are built along both edges of the embankment. The extreme outer edge is then protected by wooden planks built up like stair steps. As the water carrying the earth leaves the flumes it spreads out and its velocity is reduced. The result is that the coarser material is dropped near the edge of the embankment and the finer material is carried toward the center. The excess water is carried off by means of either pipe or a wasteway. Care should be taken that the pool of water in the center does not get too deep and that the material which settles out is made up of a mixture of fine and somewhat coarser material.

Under the hydraulic sluicing method, the most convenient and cheapest way of loosening the dirt from the hillsides above the dam is by means of the hydraulic giant, a large nozzle somewhat like that used with a fire hose, through which water is forced under high

pressure. The loosened material is then washed onto the dam by the water from the hydraulic giant, supplemented, usually, by additional water brought to the site for that purpose. The hydraulic method can be used economically only where water can either be brought to the dam site through a pipe line from a much higher intake or can be pumped through the hydraulic giant. In either case a considerable supply of water under high pressure is necessary. Occasionally the water, after dropping its load of earth on the dam, is collected in the reservoir above the dam and pumped through the giant again and again. The hydraulic method is feasible only when satisfactory material is located near the end of the dam and on higher ground, so that the water and earth may flow by gravity to the dam.

Under either method the first step is to properly prepare the foundation. The surface soil and any loose vegetable matter on the surface must be removed from the site of the dam. The space to be covered by the base of the dam should then be thoroughly plowed in order to insure a good bond between the natural earth and the embankment.

If the soil is only a few feet deep and rests on tight rock, it may be best to dig a trench about 2 feet deep into the rock along the center line of the dam before beginning to construct the embankment. This trench may be some 4 feet wide and filled with earth either puddled or tamped so that water cannot seep through the joint between rock and earth, or the trench may be narrow and filled with concrete. This is called a "cut-off wall." It should be built up into the embankment a few feet. A similar procedure should be followed if the surface soil is somewhat sandy or full of vegetable matter and rests on a comparatively tight clay subsoil.

If there is a layer of sand or gravel within a few feet of the surface, a trench should be cut through it if possible and a cut-off wall of puddled earth or concrete carried down into tight material. Where the layer of sand or gravel is so deep that this is not feasible, the best plan is to drive sheet piling of wood or metal along the line of the cut-off wall. To do this, a trench 2 or 3 feet deep should be dug the full length of the embankment and the piling driven continuously in the bottom of this trench. If the sand or gravel layer is under several feet of surface soil, the bottom of the reservoir should be puddled so that little water will seep through the bottom into the sand or gravel layer.

If sufficient good material to make the whole body of the dam reasonably watertight cannot be found, the finer material should be placed in the upper side, next to the water, and the coarser material in the lower side. No vegetable matter, such as old logs or stumps, should be used at any place in the embankment as it will decay and leave holes. If there are only a few large bowlders, they may be placed anywhere in the embankment. If there are many of them, they should be put along the lower edge or used to protect the face of the dam from wave action.

PROTECTION OF EARTH EMBANKMENTS

If the reservoir covers more than an acre or so of ground it will be necessary to protect the embankment against wave action, especially where there is much wind and where the water will be held near the top of the dam for comparatively long periods.

If large stones are available, probably the best plan is to cover the water slope of the dam with hand-placed riprap; that is, large stones placed and fitted by hand into a pavement as tight as possible on the upper slope of the dam. If plenty of coarse gravel and bowlders are available, a fairly good protection can be obtained by depositing a 12- to 18-inch layer of coarse bowlders and gravel over the water slope of the dam. Figure 3 illustrates this type of protection.

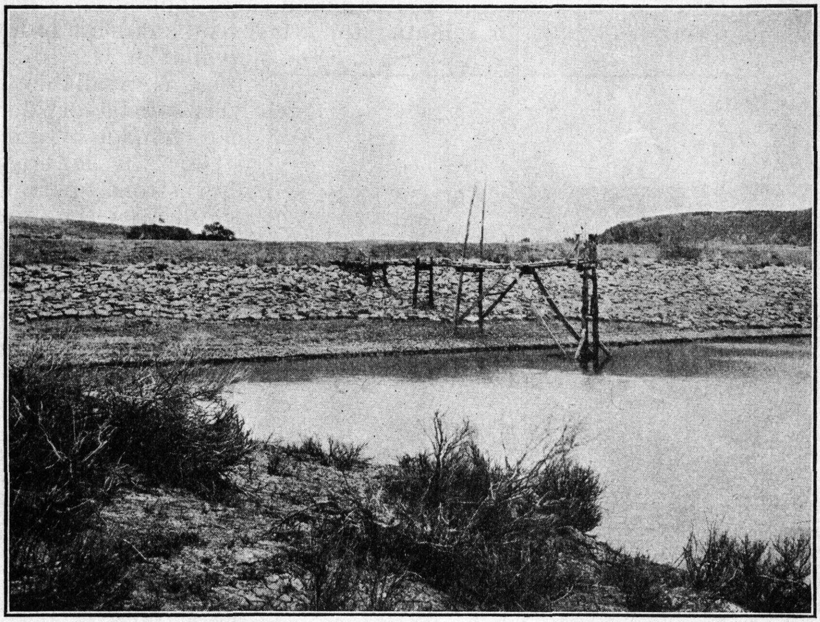

FIGURE 3.—Rock paving on reservoir slope.

If neither stone nor gravel is available, the necessary protection can be provided by a wooden fence along the upper face of the dam close to the high-water level. Such a fence is shown in figure 4. Another plan is to build two woven-wire fences close together a little below the high-water line and fill the space between them with brush or straw held down by stones or logs. Willows can sometimes be planted behind the fence and by the time the fence has rotted the willows will have grown enough to furnish the necessary protection.

Except in the more arid regions the downstream slope of the embankment may be planted to grass which will protect it from erosion by wind and rain. In areas too arid to maintain grass it may be necessary to cover the lower slope, as well as the upper, with a layer of gravel or rock to prevent erosion.

Burrowing animals sometimes endanger small reservoirs, especially those used for irrigation purposes and partly or entirely empty portions of the year. Where such rodents as muskrats, gophers, and

ground squirrels cannot be controlled by trapping and poisoning, the embankment may be protected by covering the lower slope, top, and the upper portion of the water slope with well galvanized heavy woven-wire netting of about 1-inch mesh, buried 6 inches or more below the surface to protect it from tramping.

Crayfish sometimes cause trouble by burrowing along outlet or inlet pipes. This may be prevented by placing funnel-shaped pieces of ½- or ¾-inch mesh galvanized screen around the pipe or other structure so that the crayfish will be trapped between the screen and the pipe.

ROCK-FILL DAMS

Loose rock may be used in the main body of a dam in several ways. Sometimes a dam must be constructed on an earth foundation where sufficient suitable earth for building the whole embankment is not available. If loose rock is available, a very satisfactory dam can be made by using it for the lower or downstream part of the dam. The proportion of loose rock to earth will depend very largely on the relative quantities of the materials that are easily available. If a combination dam of this sort is to be built, the best plan is to determine, before construction, approximately how much of each kind of material is to be used. The loose rock is placed first, where it will form the downstream portion of the dam, with side slopes of 1 or 1½ horizontal to 1 vertical. The earth portion of the dam is built on the upper or water side of a rock fill by the same methods and with the same care in preparing the foundation and bonding the earth fill to the foundation as if the whole dam were of earth. The upstream slope of the earth portion of the dam should be about 3 horizontal to 1 vertical, as in the earth-fill dam. Ordinarily one or more cut-off trenches are needed. One of these should be placed near the center of the earth portion of the foundation and the others properly spaced between the center line and the upstream toe.

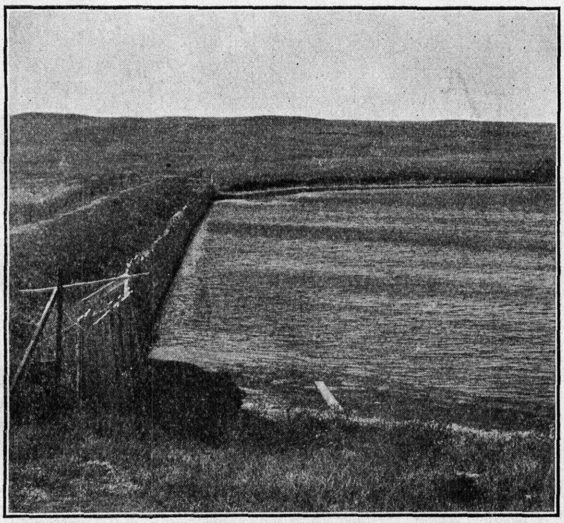

FIGURE 4.—Embankment protected by a board fence.

This type of dam will require the same sort of spillway and the same protection from wave action on the upstream face as does a dam built entirely of earth. The downstream slope, being of loose rock, will need no protection.

Sometimes little or no earth is available, whereas rock is plentiful. Generally when this is true the dam can be founded on solid rock.

All loose material at the upper edge of the site should be removed and a trench cut into the solid rock, if possible. This trench may be filled with concrete forming a cut-off wall and the concrete or wood facing of the dam may be joined to the concrete of the cut-off wall. Figure 5 shows one method of facing a loose-rock dam with timber to make it watertight.

Sometimes a dam of this kind can be covered entirely with wood, and the flood water allowed to pass over its top. Often the central portion of such a dam, directly over the river or stream channel, is made several feet lower than the abutments to serve as a spillway.

Where timber is plentiful, a combination timber and rock-fill dam is sometimes constructed. Logs are used to build cribs, in log-house fashion. These cribs are then filled with loose rocks as large as can be placed. The face of such a dam, like that of a rock-fill dam, should ordinarily be covered with planking. Sometimes the logs in the upper face of a rock-filled crib dam are hewed square so that they fit together and make a relatively watertight face for the dam.

Occasionally a dam of this sort is built on an earth or gravel foundation where it is very difficult to excavate a cut-off trench to solid rock below. In such cases either wood or steel sheet piling may be driven along the upstream toe of the dam and the upper edge of the piling connected directly with the waterproof facing of the dam.

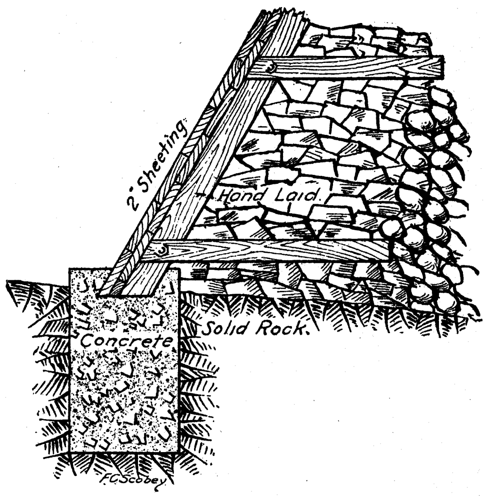

FIGURE 5.—Common method of facing rock-fill dam with timber.

CONCRETE DAMS

Sometimes it is necessary for the flood waters to flow over the top of the dam. In other cases neither large bowlders for a rock-fill dam nor suitable earth for an earth dam is available in satisfactory quantities, but gravel and sand can be obtained. Under such conditions concrete may be the best material.

Three tentative designs for concrete dams are presented herewith which, with modifications, can be adapted to a wide variety of conditions.

One may be used to good advantage in stream beds having bedrock on the bottom and sides, as shown in figure 6. In such favorable locations a concrete dam can be built cheaply with little reinforcing steel, as the greater part of the concrete is in compression. The figure shows one bank of the creek steep so the dam can be built into its rocky face. On the other side of the creek the slope is less steep so a short length of heavy wall or abutment built like a gravity-type masonry dam, is introduced to confine the dam proper to four arches. The number and length of span of these arches will depend on the width of the channel, the height to which the water is to be

raised, and other conditions. In the tentative plans shown in figure 6, the water is to be raised 12 feet above the bed of the creek, but the structure is made strong enough to resist a flood flow of 3 feet over the crest of the dam, making a total depth of 15 feet. The bed width of the channel is divided into 4 parts with 3 buttresses as shown. These buttresses are embedded in the rock in order to prevent sliding, and two steel reinforcing rods extend from 3 feet below the bed of the creek up through the entire height of each buttress to prevent overturning and to relieve the concrete of tensile strain. Both the arch sections and the gravity section are embedded in the solid rock where

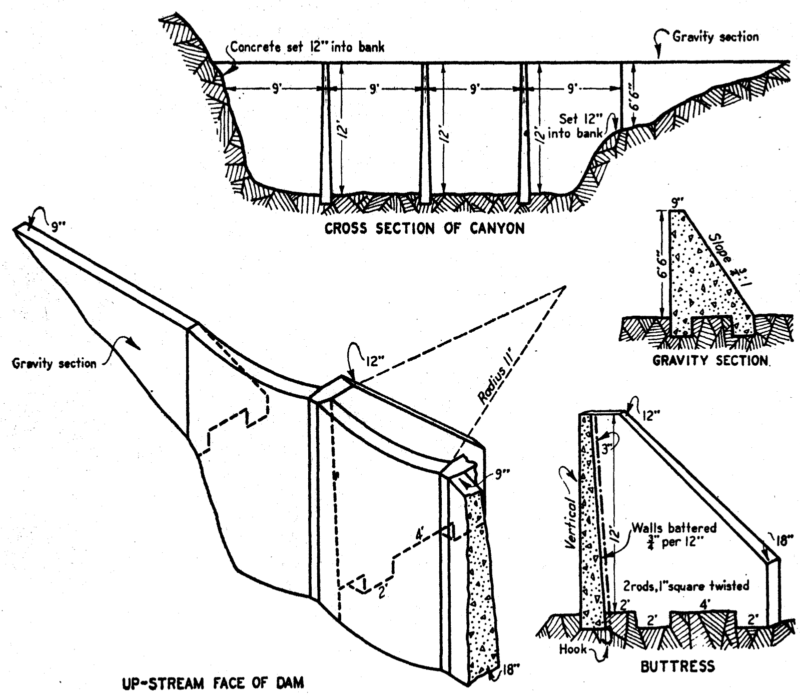

FIGURE 6.—Concrete dam for rocky stream bed.

they join the bottom and sides of the channel, to afford greater strength and to prevent leaks.

In the second tentative design, shown in figure 7, bedrock is too far below the surface to serve as an anchorage and watertight connection. The chief problem, apart from the stability and permanence, is to prevent water escaping either under or around the structure. When a small stream finds its way under or past the end of a dam it is likely to erode the finer material and thus enlarge the opening until a large volume of water passes through and the dam is wrecked.

To safeguard the structure against a possible failure of this kind, a cut-off wall of concrete extends not only far below the bed of the creek but also into the banks. The wall forming the dam proper is supported by an abutment on each side and by three buttresses. Such a dam must be safeguarded also against the action of water falling over the crest upon the earth and gravel in the bed of the stream. This protection is provided by extending the floor and sides

of the dam downstream and by riprapping the channel—covering the bottom and banks with a layer of stone—beyond the lower end of the structure. The plan shown is designed to hold 12 feet of water in the reservoir and to pass 3 feet over the crest during floods. The concrete is reinforced throughout, and the structure is believed to be amply strong to withstand all ordinary requirements.

It is sometimes necessary to provide a practically unobstructed passage for the stream in order to pass floods during the winter or spring months, closing the stream channel after the heaviest flow is past and conserving water for later use. Figure 8 shows a plan for a concrete structure with wooden flashboards to close the opening. It is designed to permit a maximum depth of 2 feet of water flowing over the flashboards. Such a dam is sometimes useful for diverting

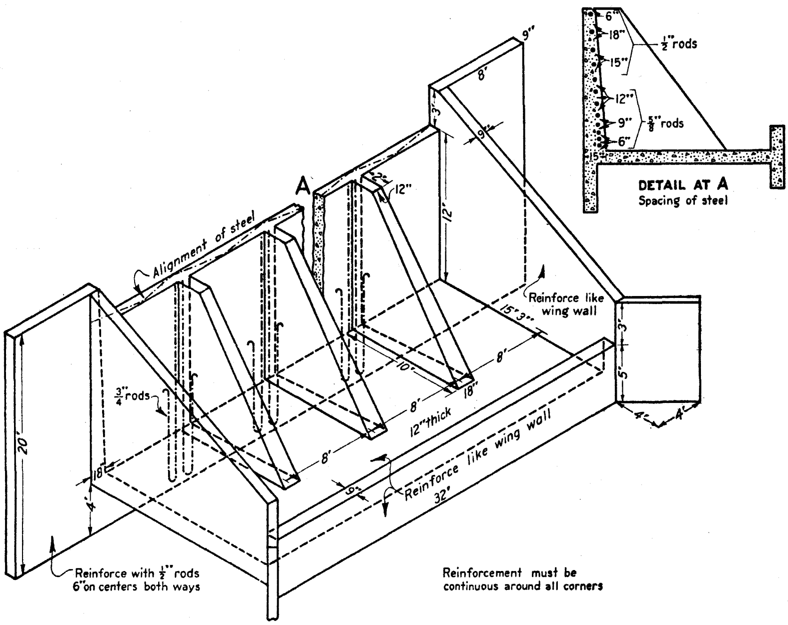

FIGURE 7.—Concrete dam for gravelly stream bed.

water from a stream channel into an irrigation ditch. This design is suitable for a firm earth or gravel foundation. If the foundation material is fine sand or silt, the floor of the dam should extend farther downstream. The channel below the dam will need to be protected by riprap as well as by the wing walls and shallow cut-off wall shown.

In a canyon with bottom and sides of solid rock, the piers can be used without the floor and abutments. If this is done, the reinforcing rods in the nose of each pier must be firmly anchored into the rock floor by grouting or otherwise. Unless this is done the piers may tip over. In addition, the piers should be set into notches in the rock foundation, as shown in figure 6, to prevent their sliding downstream.

Each flashboard is 6 feet long and has an eyebolt at each end for handling. Two men, one at each end of the boards, will usually be required to place them while water is flowing, but one man can

remove them. Short poles with hooks to fit into the eyebolts are used. Foot planks should be fastened to the tops of the piers.

OUTLET AND INLET STRUCTURES

The outlet from a small reservoir will usually be through some sort of pipe. The gate controlling the flow through the pipe should be placed at or near the upper end, otherwise a leak in the pipe would allow water under pressure to escape into the body of the dam and very likely cause its destruction. If the foundation is solid and firm, so that the load imposed by the embankment will not cause it to settle, a concrete pipe of good quality is suitable for an outlet. If the soil is highly charged with alkali or is highly acid, it may be desirable to use vitrified-clay sewer pipe.

If the foundation is likely to settle, some pipe less brittle than concrete or clay should be used. Probably the most permanent pipe

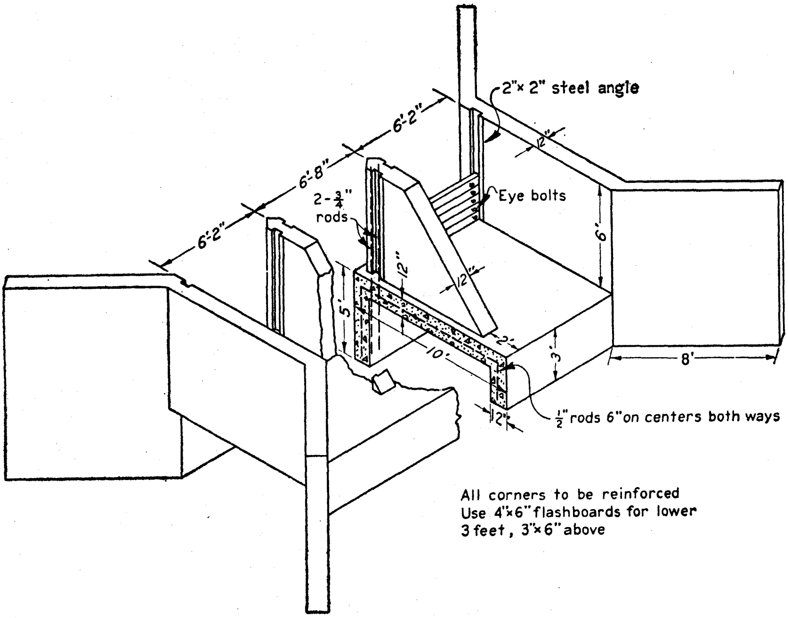

FIGURE 8.—Dam with flashboards.

is cast iron, but this is expensive, especially if the freight haul is long. For this reason, cheaper pipes are generally used. Creosoted wood-stave pipe or corrugated galvanized-iron pipe may be used. Either should have a life of 15 to 25 years.

The outlet pipe should be laid, if possible, in a trench dug in the solid ground under the embankment. Cut-off walls or collars should be constructed around it. Ordinarily these walls may be made of concrete, and for the usual small reservoir need not extend more than 1 foot or 18 inches out from the pipe. In most cases 2 or 3 such cut-offs around the outlet pipe will suffice. The earth should be packed carefully around the pipe to prevent water from percolating along it and endangering the dam.

If the outlet gate is put at the upper end of the pipe line, it will be necessary to build out from the embankment to a point directly over the end of the pipe a bridge from which the valve can be manipulated. If the embankment is very low, the gate stem may be laid diagonally up the slope, but usually this is not the best plan.

In all cases some sort of screen or grillage should be provided around the upstream end of the outlet pipe to prevent trash from entering it. If the pond is to be stocked with fish, it will be necessary to use a comparatively fine-meshed screen so that small fish will not be drawn out of the pond. If a fine-mesh screen is necessary it often will be desirable to place a coarser screen a short distance above it. Provision must be made for withdrawing the screens for cleaning when necessary.

If water enters the reservoir by gravity the inlet is usually a ditch, but if the supply is pumped the inlet pipe should be carried through the embankment. If it is carried over the embankment the pumping lift and the cost are increased unnecessarily. If the inlet pipe is placed in or under the embankment, the precautions already described for outlet pipes should be taken to prevent rupture by the weight of the material and to keep water from percolating along the pipe.

SPILLWAYS

The location of the spillway is particularly important. If the dam is in the bed of a stream, the spillway must have sufficient capacity to pass the largest flood that is likely to occur. Perhaps the most practical method of determining the size of a spillway is to examine the stream channel for high-water marks. If these can be found, the cross-sectional area of the stream at extreme high water can be estimated and the size of the spillway based on this. A spillway will carry water off as fast as a stream channel free from obstructions and having the same cross-sectional area, provided it is given as much fall as the stream bed. The spillway should be larger than the stream channel in order to provide for extraordinarily large floods.

If possible the spillway should be located entirely apart from the dam. Sometimes it is possible to use a natural saddle some distance from the dam, and if the spillway can be excavated in solid rock no lining will be required. If the water from the spillway can be returned to the main stream a considerable distance below the dam, so much the better.

If the spillway must be located at one end of the dam, great care should be taken to make sure that water will not undermine the lower toe. The spillway should, if possible, be excavated in solid rock, otherwise it must be lined with concrete or some other material which will not be eroded. The lining should extend far enough downstream to prevent any possibility that the water will cut a channel back into the reservoir.

For very small reservoirs it is sometimes safe to allow the overflow to discharge over a grassy slope that is not too steep.

If the dam is built in a depression apart from the stream channel, or if the reservoir is on a smooth slope or level ground and fed from a canal, a spring, or a pumping plant, the problem is much simpler. Often in such cases no spillway is required, but it is best to provide one large enough to take care of the maximum flow into the reservoir.

RESERVOIR LOSSES

Water losses from reservoirs occur through evaporation from the surface, seepage through the sides and bottom, and leakage through the outlet gate.

In reservoirs lined with concrete or other impervious material, the evaporation losses are the only losses of importance. Evaporation losses for each 24 hours range from nothing, during rainstorms and on cool, damp days when the air is saturated, to a maximum of perhaps one half inch in depth over the water surface during extremely hot and windy periods.

Seepage losses, on the other hand, range from a minimum of one half inch per day to a maximum of 1 foot or even more per day. In most cases a reservoir losing the latter amount would be almost useless. Even where the material of which the dam is constructed is reasonably satisfactory, losses by seepage are often very important. It is therefore desirable to decrease them as much as possible.

As previously stated, the most watertight and satisfactory material for a reservoir is a sandy or gravelly clay, which can be packed so as to be almost watertight. If the reservoir bed is naturally of such materials, all that is needed to make it hold water is to pack it thoroughly. If the water is not to be used for domestic purposes, the best method of packing the bottom is by bedding or feeding sheep on the reservoir site when the earth is wet.

If the bed is not clayey it is sometimes practicable to line it with clay a few inches thick. If a deposit of pure clay is easily accessible, a layer 3 or 4 inches thick can be spread over the bottom and sides of the reservoir and mixed with the surface soil by disking or harrowing. If the whole reservoir bed is then packed by rolling or tramping by stock the lining will be very satisfactory. Here again the use of sheep is recommended.

Where the water supply is drawn from a surface stream which carries fine sediment such as clay or silt, a seal will gradually be formed over the sides and bottom. If a stream carrying a heavy load of coarse sediment is diverted into a reservoir the latter may be filled too rapidly with sediment, It is sometimes possible to draw off the water from near the surface, which carries only the finer sediment, and let the coarser sand and gravel be carried on down the stream.

For a small reservoir, especially when the water is to be used for domestic purposes, some other type of lining may be preferable. Ordinarily concrete will be most satisfactory. If the lining is not reinforced, it should be from 2 to 4 inches thick. The lining should be placed in blocks or squares 15 to 20 feet in each dimension with expansion joints at their edges to prevent formation of cracks that will allow water to leak out. Several types of such joints are shown in figure 9. Complete watertightness can be secured by casting a corrugated strip of copper or lead into the joint. In some cases it is well to use a layer of woven wire to reinforce the lining.

A thin but watertight lining, called gunite, is made by spraying a mixture of sand, cement, and water on woven-wire reinforcing with a special device using compressed air. Provision should be made for expansion and contraction of gunite lining unless it is heavily reinforced with steel. The use of heavy woven-wire reinforcement does not entirely prevent the formation of cracks as the concrete shrinks, but the cracks are so small that they do not permit the loss of water.

The principal danger with a concrete-lined reservoir is that water leaking through the lining will saturate the earth just under the concrete. Then, if the reservoir is empty when freezing weather comes, the water in the soil will freeze and heave, rupturing the lining. If the material in the reservoir bed and banks is porous sandy soil or gravel, there will be little danger from heaving. The rupture of the lining by frost heaving can be prevented by one of three methods: (1) Care can be taken in making the lining watertight, so that no leakage occurs; (2) a thick layer of coarse gravel may be placed just under the lining, permitting the water which leaks through the lining to drain away; (3) in some instances draintile may be laid outside the lining to carry off the water.

PREVENTION OF SILTING

In some sections reservoirs fill up rapidly with silt. There are several methods of preventing this. Sometimes it is possible to build a channel around the reservoir and divert the flood waters, carrying the larger amount of silt after heavy rains, through this channel. After the heaviest load of silt has passed, the clearer water is turned into the reservoir. In other cases, especially if the reservoir is long and comparatively narrow, it is possible to sluice out a good deal of the silt which collects during one or more seasons, by installing large gates at the bottom of the dam and opening them during the high-water period. The water rushing through them will carry out much of the silt.

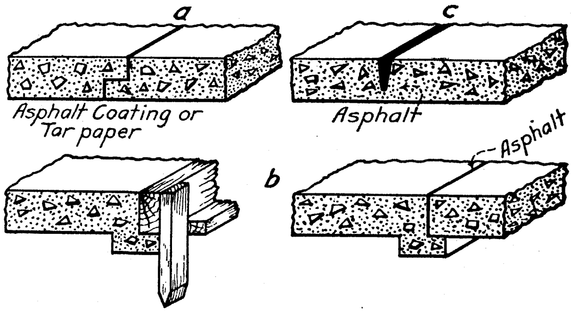

FIGURE 9.—Types of joints used in concrete linings for reservoirs; *a*, ship-lap joint; *b*, reinforced-lap joint; *c*, V-joint filled with asphalt.

Sometimes the filling of a reservoir with sediment can be delayed or prevented by changing conditions on the watershed above. If the watershed which supplies a small reservoir is allowed to grow up to grass or timber, there will be much less erosion and the reservoir will silt up more slowly. In parts of the Western States where the public range has been very heavily overgrazed, erosion is serious and reservoirs silt up very rapidly. Often if an area is protected from livestock for a few years, the grass cover will be renewed and erosion will be decreased.

MAINTENANCE OF RESERVOIRS AND DAMS

Dams and reservoirs must be properly maintained if they are to remain useful. An earth embankment must be kept up to its full height and width. Often, especially on smaller reservoirs, the tramping of stock and the erosion caused by wind and rain wear down the embankment until waves or floods may overtop and destroy it.

The burrowing of gophers and ground squirrels near the top of an irrigation reservoir, or of muskrats and crayfish along the outlet

structures below the permanent water line, must be continually guarded against and such burrows closed before serious damage is done. Small leaks caused by this burrowing can not be stopped from the outside. The best plan is to dig a trench on the inner slope, just above the water line until the hole is found. The hole and trench can then be filled with good earth well compacted.

At least once a season, when the water is low in the reservoir, the outlet gate and structure should be carefully examined and repaired if necessary.

The spillway should be examined periodically to make sure that it is not obstructed. If it adjoins an earth embankment or is constructed in earth where its failure would endanger the reservoir, it should be examined for leaks and necessary repairs should be made.

If fish are to be kept in a reservoir the spillway must be screened. If the reservoir is not in the stream channel there will be no particular difficulty in maintaining the screens, but in a reservoir in the bed of a natural stream, the screen may be clogged during high floods, causing the water to overflow the dam and destroy it. A possible solution is to put the screen on posts, as in building a woven-wire fence, at some distance above the spillway. If this screen is built to a moderate height above the bed of the spillway it will prevent the fish from being carried out of the reservoir by small outflows. A big flood will overflow the screen and go on through the spillway, and may carry the fish out of the reservoir but this would be better than the destruction of the dam.

If the water is to be used for domestic purposes the reservoir must be fenced and livestock prevented from contaminating the water. If the water is to be used only for watering livestock, it will be much better to draw it out of the reservoir, through a pipe, into watering troughs below rather than to give the stock access to the reservoir itself because they will trample down the banks and may even destroy them. Moreover, the water will be contaminated and much of it will be lost in the muddy area around the edge, if the livestock have access to the reservoir.

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